STATUS OF SUPERCONDUCTING RADIOFREQUENCY SEPARATOR CRYOGENIC SYSTEM

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Abstract

The OKA experimental complex proposing to use the technique of RF beam separation to produce a Kaon beam is under construction at IHEP. Two deflecting superconducting niobium cavities operating at 1.8 K are the basic elements of the separator. To provide cooling at this temperature commercially available 500 W, 4.5 K helium refrigerator is used to cool liquid helium bath of the satellite refrigerator. The last one is actually a big warm up heat exchanger with flow imbalance and very low pressure drop. Vacuum group consists of two stages of roots blowers and one stage of rotary slide valve pumps. Pump stages are separated by intermediate gas coolers. The schematic, thermodynamics, design capacity and current construction status of the cryogenic system are presented.

INTRODUCTION

In January, 1998, two cryostats with niobium superconducting deflectors were transported from CERN to IHEP to be used as the basic elements of the radiofrequency separator for production of separated K-mesons [1]. Working temperature of deflectors is 1.8 K and an estimated total heat load at this temperature level is about 250 W. Taking into account high cost of a cryogenic system of this capacity it was decided to take all appropriate measures to reduce the price of the system. Main solutions in this direction were:

- to use cryogenic and vacuum equipment produced in Russia
- to refuse construction of new buildings and to place cryogenic system equipment in the already existing buildings situated close to the separator location
- to use already existing equipment for helium storage, purification and compression in spite of there is rather big distance (~ 1 km) from this equipment to the helium refrigerator.

A special cryogenic test facility was built up at IHEP for inspection tests of the cryostats with deflectors [2]. At this facility cryostats were initially cooled down to 80 K and vacuum leak tested. Then they were tested at 4.2 K, this time cavities were RF powered. Adding the vacuum pumping group to the test facility allowed to perform tests at lower temperatures. For example, it is possible to keep cavity at 1.8 K as long as 2 weeks. Recently cavity is stably cooled at 1.6 K. Experience gained during development, construction and operation of this test facility was very useful in the work on the separator cryogenic system development.

GENERAL SYSTEM DESCRIPTION

Cryogenic system simplified flowchart is shown in Fig. 1a.

The superconducting cavities are cooled by a satellite refrigerator which consists of the large vacuum heat exchanger HEX1, liquid helium bath and of two small heat exchangers HEX2 located close to the each cryostat with deflector. The word “satellite” is used here to stress that such a refrigerator having no gas expanders can not produce cold at the liquid helium temperature level without external source of cold. Typically another refrigerator equipped with turbines works as an external source of cold. In our case commercially available helium refrigerator of KGU-500 type provides this external cooling. It cools liquid helium bath at about 4.5 K. Temperatures below 4.5 K (down to 1.8 K) are reached by pumping helium vapor. A system of vacuum pumps (“pumping machine”) is used to pump helium gas. Cold of the helium vapor is recuperated in the heat exchangers of the satellite refrigerator.

Thermodynamic cycle of the satellite refrigerator is shown schematically in Fig. 1b.

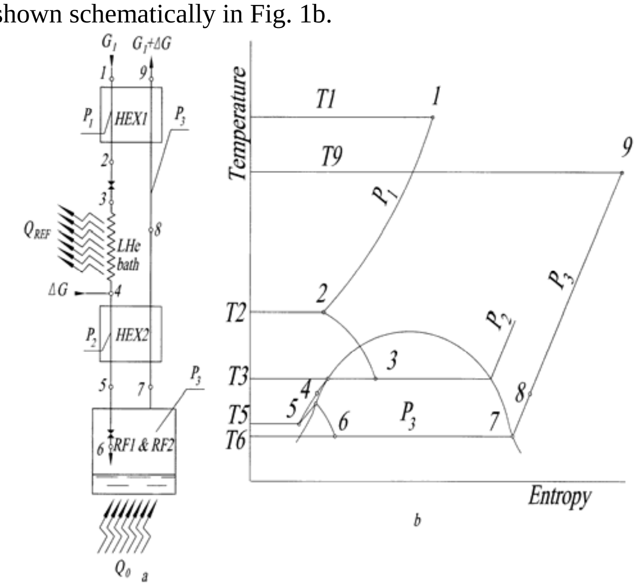

Figure 1: Separator cryogenic system flowchart (a) and thermodynamic cycle (b)

System Operation

After compressors pressurized helium gas flow is divided in two parts. One part at pressure of 28 bar is used in helium refrigerator KGU-500 where helium is liquefied into the dewar. Another part with mass flow rate G_1 goes to the inlet of the heat exchanger HEX1. After passing all heat exchangers of the refrigerator KGU-500 and heat exchanger coil of the liquid helium storage vessel helium flow at about 25 bar and 4.5 K is fed along a short cryogenic transfer line to the expansion valves in the liquid helium bath. One J-T valve is opened enough to keep the level of liquid helium in the bath. Mass flow rate through another J-T valve is ΔG, that is flow imbalance of the heat exchanger HEX1. This flow imbalance improves the efficiency of the HEX1. Helium vapor from the liquid helium bath and from the storage dewar returns to the heat exchangers of the refrigerator.

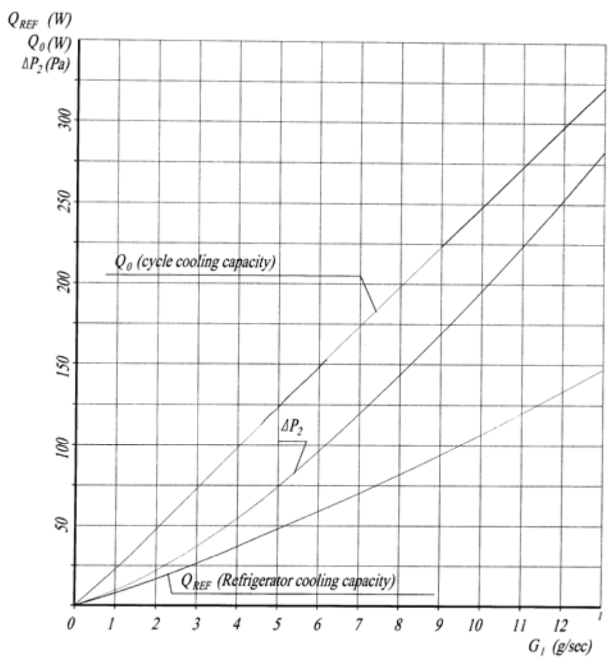

Figure 2: Cooling capacity of the system and low pressure flow pressure drop.

There are two coiled heat exchangers in the liquid helium bath: main and auxiliary. Pressure in the bath is about 1.05 bar, and pressure of helium flows in these heat exchanges should be somewhat higher to have subcooled liquid at theirs exits and at the inlets into the low temperature heat exchangers HEX2 located near the cryostats with deflectors.

High pressure flow of the satellite refrigerator is cooled by low pressure helium gas in the large vacuum heat exchanger HEX1. After expansion in J-T valve in the liquid helium bath and after cooling in the main heat exchanger of the bath this flow G_1 is mixed with imbalance flow ΔG. Along a cryogenic transfer line this mixed flow comes to the distribution box from which it is distributed to the low temperature heat exchangers HEX2 of the cryostats RF1 and RF2. In these heat exchangers, incorporated into the transfer line, liquid helium flow is cooled down to the final expansion temperature. After expansion in the J-T valves, located in the cryostats RF1 and RF2, liquid and vapor separate. Superfluid liquid replenishes the helium vessels of cryostats. Vapor, after passing through the low temperature heat exchangers, cryogenic transfer line and large vacuum heat exchanger, has temperature close to the room temperature. An electric heater at the exit from the large vacuum heat exchanger heats up helium gas to the ambient air dew point. Then gas is pressurized by pumping machine and returns to the gasholders. Low pressure flow from the KGU-500 refrigerator returns to the same gasholders, but through the separate pipe line. Gasholders are connected with suction of the main compressors, so at this point cooling cycle is closed.

System Cooling Capacity Estimation

To determine most suitable operation parameters a computer model of the cryogenic system was developed. It includes the verificatory calculations of the counterflow heat exchangers HEX1 and HEX2 and calculations of the thermodynamic cycle. Subroutines for calculating thermophysical properties of helium were used in this computer simulation.

The heat transfer surface areas and characteristic dimensions of the channels of the heat exchangers sections were determined taking into account the real geometry of the pipes tightly wrapped with a spiral wire.

The heat transfer surfaces of the both upper and lower sections of the heat exchanger HEX1 as well as the heat transfer surface of the heat exchanger HEX2 have been divided into 500 portions to reach the required accuracy of the flows inlet and outlet temperatures calculation. In the used iteration algorithm an absolute accuracy of temperature calculation for the single portion of a heat transfer surface was about 10^{-8} K. Calculation accuracy for the inlet and outlet flows temperatures of the heat exchanger as a whole was about 10^{-4} K. Relative inaccuracy of the heat balance calculations was 4% at the most.

Satellite refrigerator (or cycle) cooling capacity Q_0, required cooling capacity of the KGU-500 refrigerator Q_{REF} and total low pressure flow pressure drop ΔP_2 were considered as the main parameters. These parameters calculation results versus satellite refrigerator high pressure flow mass flow rate G_1 are presented in Fig. 2 for the relative flow imbalance $\Delta G/G_1$ of 10%, cooling temperature 1.8 K and 14 bar helium pressure at the inlet into the satellite refrigerator. These results show that the developed cryogenic system has a considerable margin concerning KGU-500 refrigerator available cooling capacity. Total low pressure flow pressure drop is within the specified limits.

Figure 3: Helium refrigerator, large vacuum heat exchanger and liquid helium bath (last two in the background) during erection

STATUS OF WORK

To date main subsystems projects are developed, many of them already manufactured or purchased. Installation work is in progress, tests and commissioning of subsystems being prepared with an aim of gradual integration of them into a complete system.

Helium refrigerator of the KGU-500/4,5-140 type (500 W at 4.5 K or 140 l/hr of liquid helium) was delivered by “NPO Geliymash”, JSC. Work on the refrigerator piping is close to finish (Fig. 3). Upgrading of the helium storage, compressing and purification systems are in progress. Commissioning tests of refrigerator are planned to be performed in November this year. At the same time liquid helium bath cryostat will be tested.

Large vacuum heat exchanger is very similar to the heat exchanger delivered to DESY by IHEP [3]. Heat exchanger is manufactured, installed and connected by pipe lines with other cryogenic equipment according the project.

Sections of the helium cryogenic transfer line about 100 m in total length were manufactured by “Cryogenmash”, JSC, according IHEP technical specifications and delivered to IHEP. Small heat exchangers HEX2 were manufactured by IHEP, delivered to “Cryogenmash” and built into the appropriate transfer line sections. An agreement with “Cryogenmash” on transfer line mounting and testing is under preparation.

REFERENCES

[1] “Superconducting Separator Emerges from Sleep”, CERN Courier, v.38, No.3, April 1998, p.12.

[2] Bakay A.I. et al., “Cryogenic 1,8 K Test Facility for Cryostats with Superconducting Cavities of RF-Separator”, RUPAC-2002, Obninsk, October 2002, p. 445.

[3] E. Kashtanov et al, “Large Low Pressure Heat Exchanger for the TTF Cryogenic System”, ICEC18, Mumbai, February 2000, p.315.